DOCUMENT RESUME

ED 081 392 HE 004 578

AUTHOR	Weathersby, George B.; Weinstein, Milton C.
TITLE	A Structural Comparison of Analytical Models for University Planning.
INSTITUTION	California Univ., Berkeley. Ford Foundation Program for Research in Univ. Administration.
SPONS AGENCY	Ford Foundation, New York, N.Y.
REPORT NO	Pap-P-12
PUB DATE	Aug 70
NOTE	52p.
AVAILABLE FROM	Ford Foundation, 2288 Fulton Street, Berkeley, California 94720
EDRS PRICE	MF-$0.65 HC-$3.29
DESCRIPTORS	*College Planning; Colleges; *Decision Making; *Educational Finance; *Educational Planning; *Higher Education; Models; Universities

ABSTRACT

This paper provides a conceptual framework for the evaluation of analytical planning models designed for application in institutions of higher education. In an attempt to address the most important and difficult decisions facing managers of higher education, the majority of the analytical models that have been recently developed have focused upon the operating or capital budgets of the institution. The larger models have attempted to be comprehensive in dealing with all the expenditure components of the institution while a number of specialized models have addressed specific components of the institution in greater depth. This paper classifies the structure and scope of the models reviewed in seven major categories: (1) the function or purpose of the model; (2) the theoretical foundation for the particular formulation; (3) the mathematical techniques used; (4) the subject or subjects of the model; (5) the sources of data; (6) the previous and current uses of the model; and (7) the operational status of the model. After defining these terms, the paper presents a structural comparison along these major dimensions in tabular form to facilitate an evaluation of these analytical models. The major distinguishing characteristics of each model are then discussed. The paper finishes with a summary and conclusion which incorporates the author's recommendations for future research and development. A 53-item bibliography is included. (Author)

FORD FOUNDATION PROGRAM FOR RESEARCH IN UNIVERSITY ADMINISTRATION

Office of the Vice President—Planning
University of California

FORD GRANT NO. 680-0267A

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ED 081392

A STRUCTURAL COMPARISON OF ANALYTICAL MODELS FOR UNIVERSITY PLANNING

George B. Weathersby

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Paper P-12

August, 1970

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PREFACE

This is one of a continuing series of reports of the Ford Foundation sponsored Research Program in University Administration at the University of California, Berkeley. The guiding purpose of this Program is to undertake quantitative research which will assist university administrators and other individuals seriously concerned with the management of university systems both to understand the basic functions of their complex systems and to utilize effectively the tools of modern management in the allocation of educational resources.

This paper provides a conceptual framework for the evaluation of analytical planning models designed for application in institutions of higher education. This framework is then used to compare many of the best known mathematical models currently available and to give some indication of their comprehensiveness, structure, mathematical approach and relative desirability. An extensive bibliography is included.

This paper will be presented at the Eleventh American Meeting of the Institute of Management Science in Los Angeles, October, 1970.

I. INTRODUCTION

Higher education is being called to account by almost every constituency. The rising levels of dissatisfaction and disaffection experienced by students, faculty, trustees and politicians have exacerbated both the external acquisition and the internal allocation of resources. Higher education is currently a thirty billion dollar a year enterprise which includes more than seven million students, faculty and staff. Managers in higher education have recently turned to program budgeting and analytical models to sharpen their control and understanding of their institutions and of the effects of their decisions on the course of such a massive and complex enterprise. This paper provides a structural comparison of many, but by no means all, of the analytical models currently available to decision makers in higher education.[1]

The early 1960's was a period of tremendous expansion of higher education with the arrival in college of the war babies, the high level of defense research expenditures and the generous cooperation of many state legislatures. On the contrary, the late 1960's and early 1970's have been characterized by financial stringency, a reduction of federal research expenditures and the use of the university as a political instrument by many participants. The present posture of nearly every major institution is one of tense co-existence with its funders; the manifest source of tension is the budget, but a variety of institutional activities and objectives[2] are

[1] For a thorough review of the literature of higher education planning prior to 1968, see K. Hüfner, "Economics of Higher Education and Educational Planning - A Bibliography," [50].

[2] See D. W. Breneman and G. B. Weathersby, "Definition and Measurement of the Activities and Outputs of Higher Education," Ford Foundation Research Program in University Administration, Discussion Paper No. 10, University of California, for a fuller discussion and taxonomy of institutional activities, outputs and objectives.

discomforting to other public officials.

At issue is not only the operational management of institutions of higher education, but also the very role, purpose, nature and concept of each institution. Many funders and some managers of higher education recognize that the institutional budgets embody the values and objectives of the institution and describe its intended future evolution. In other words, the capital and operating budgets are instruments both of planning and of control--which are the essence of current institutional conflict. As is often the case in management science, the analyst must decide whether to look for problems with easy solutions or to engage crucial problems on some uncharted sea. While the former is the more comfortable (and usual) course, the latter may well prove to be the most productive.

In an attempt to address the bureaucratically most important and difficult (although analytically most tractable) decisions facing managers of higher education, the majority of the analytical models that have been recently developed have focused upon the operating or capital budgets of the institution. The larger models have attempted to be comprehensive in dealing with all the expenditure components of the institution while a number of specialized models have addressed specific components of the institution in greater depth. For example, several models have been formulated just to forecast student enrollment or faculty distribution. The mathematical complexity of the various models varies from simple addition and multiplication to sophisticated optimization techniques. The functions, underlying theory, methods, subjects, sources of data, uses and operational status of the currently available models all vary considerably. After defining these terms, this paper presents a structural comparison along these major dimensions in tabular form to facilitate an evaluation of

these analytical tools. The major distinguishing characteristics of each model are then discussed. Finally, we give a summary and conclusion which incorporates our recommendations for future research and development.

II. DEFINITIONS

The specific terms used to classify the structure and scope of the mathematical models we have reviewed fall into seven major categories: (1) the function or purpose of the model; (2) the theoretical foundation for the particular formulation; (3) the mathematical techniques used; (4) the subject or subjects of the model; (5) the sources of data; (6) the previous and current uses of the model; and (7) the operational status of the model. Each of these major categories is divided into several specific items which will be described below.

Function

A mathematical model can be used in several different modes. Some models are designed to *derive* measures of system cost or activity; e.g., cost per student, degrees granted per student enrolled, cost per degree and students per faculty member. Alternatively, some models combine a set of operating parameters, which are assumed constant throughout the planning period, (perhaps with a forecast of future demand) and *project* factors contributing to institutional expenditures for each year in the planning horizon. A few models ask the question, given a fixed or anticipated amount of resources, how does one best *allocate* these resources among the various alternative uses? This requires an explicit value structure which describes the relative importance of each alternative use. These categories are not mutually exclusive and it is conceptually possible to structure analytical models to perform all these functions.

Theory

The observer of institutional activities who seeks to analyze their salient characteristics has several options available. He can collect quantitative data on a large number of variables and through statistical correlation he can choose a set of regression coefficients which then constitute his predictive model. This approach requires no theoretical foundation and no *a priori* conceptual model other than assuming that the future will mirror the past.

On the other hand, one can approach the analytical modeling of institutional activities from a number of existing conceptual bases. Several models use individual decision making as a paradigm. These *behavioral* formulations are based either on *economic market* considerations or on *preference* or decision theory[3] considerations. These models aggregate individual decision units to describe institutional decisions; in contrast, a much larger group of models describe the macro *growth forces* of the institution by applying either a *trend* or *growth index* to the current activity levels. Such macro models do not attempt to explain the determinants of growth but simply observe the existing or externally apparent relationships. Finally, some models treat the *equilibrium* behavior of institutions of higher education responding to the various socio-economic forces.

Method

Mathematical models can be classified into either optimizing or non-optimizing categories depending upon whether or not an objective function

[3]See H. Raiffa, Decision Analysis, Addison-Wesley, 1968.

is explicitly included and maximized. In the area of higher education, the recently developed optimizing models have been applications of *mathematical programming*, including *linear*[4] and *nonlinear programming*,[5] *dynamic programming*[6] and *optimal control theory*.[7] An important related topic is the *analysis of uncertainty*, which investigates the stochastic properties of institutional activites.

Most models of higher education, however, are *simulation* rather than optimization models because no explicit objective function is included. Basically, simulation models attempt to associate cause with effect, action with reaction, policy with result through the use of mathematical formulae. Some models permit *user intervention* at every stage of the calculations to modify the numerical results or structural form prior to subsequent calculations, while most models are *autonomous* and automatically simulate the system for the chosen number of years. Simulation models may be either completely certain or stochastic, depending upon their exclusion or inclusion of uncertainty. Stochastic systems may be simulated by *Monte Carlo* techniques.

Independent of the analytical use of the model, the conceptual formulation and numerical estimation of the equations which describe the relevant segments of higher education draw upon a number of specific techniques. Some simulation models utilize statistical *regression*, both classical and Bayesian, to estimate their forecasting equations while these parameters

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[4]See G. Hadley, Linear Programming, Addison-Wesley, 1962.

[5]See G. Hadley, Nonlinear and Dynamic Programming, Addison-Wesley, 1964.

[6]See R. Bellman, Dynamic Programming, Princeton, 1957.

[7]See A. E. Bryson and Y. C. Ho, Applied Optimal Control, Blaisdell, 1969; also G. B. Weathersby, "The Allocation of Public Resources: A Decision and Control Analysis," unpublished Ph.D. thesis, Harvard University, Cambridge, 1970, for applications to public sector decisions.

may be *user supplied* in other models. Other frequently used paradigms are *Markov* models,[8] which are probabilistic transition models, and *input-output* models, which are deterministic linear transformation models.

Subject

The spectrum of subjects addressed by mathematical models currently available for higher education ranges from the global considerations of national educational planning to the question of how long a book should be stored on a library shelf. It is useful in classifying models to identify which of the primary programs of *instruction*, sponsored or *organized research*, and *public service* or of the secondary programs of *administration and support* programs are included in the model.[9] Models which address the instructional program focus on *students*, *faculty*, and their interelationship through student/faculty ratios, contact hours, workload policies, staffing policies, and similar institutional characteristics. Organized research and public service activities are usually characterized by their total dollar expenditures and the number of personnel involved. For the purposes of classification, we have disaggregated the administration and support program into *libraries*, *student services and activites*, and *other general support*.

Resources consumed by institutional activities include both *physical space* and *financial* considerations. The financial aspects of institutions of higher education encompass *operating costs* and *revenues*, *other institutional fund sources*, and *capital outlay* for physical construction.

Most models focus on the cost components of these subjects and very few

[8] D. J. Bartholomew, Stochastic Models for Social Processes, Wiley, 1967.

[9] See WICHE, "Program Classification Structure," Technical Report No. 13, 1970, for a full discussion of the allocation of institutional activities to these major program categories.

contain any explicit consideration of outputs of non-economic activity levels. Very few models address the issues of curriculum, academic requirements, or detailed personnel actions. Also, very few models have faculty assignment or classroom utilization algorithms.

Sources of Data

The *special purpose collection* and processing of the data necessary to drive a large mathematical model is often both expensive and time consuming. Therefore, the costs would be significantly different if an institution had an *automated* data collection system which could provide the relevant data on a regular and periodic basis. In addition, most models provide the option of the user personally supplying all of the requisite data based upon his subjective assessments.

Uses

Models which are specifically designed to aid in the management of a single institution usually include *academic, fiscal,* or *physical planning*--or all three. National or regional models usually include either regional economic development or considerations of *manpower requirements* by various employment specialties. Specialized models address materials inventory, library storage, facilities allocation and other *scheduling* problems.

Status

Most of the analytical models reviewed in this study are *research efforts only* although a few are *currently operational* in an institution of higher education.

In addition, there is considerable diversity in the maximum level of detail employed by the various models. Most models work with large aggregations of academic departments, several permit aggregations into the Higher Education General Information Survey discipline specialties, while a few permit the user to define the level of disaggregation at the program, sub-program or activity (e.g., 1 lecture, or 1 lab section of 1 course) level. Some models classify students by major field of study and academic level (e.g., freshmen, sophomores, etc.). Similarly, faculty is often disaggregated by rank and discipline (e.g., a full professor of biological sciences).

III. STRUCTURAL ANALYSIS OF MODELS

The following tables present in summary form the salient features of each of the models considered in this paper. Table I summarizes the general function, operating theory, mathematical methods, subjects of decision-making, planning data sources, uses and present status of the models. Table II delineates the lowest level of aggregation of many variables used in the models. All of the major models aggregate these variables into the larger categories shown in Table II. The reader should bear in mind that the attributes credited to a particular model may exist at various levels of development, ranging from mere conceptualizations of particular lines of analysis to fully-tested model components. Furthermore, these tables point out some of the needs for the future development of models of educational institutions.

For purposes of discussion we shall divide the literature of higher educational planning models into three groups. First, and most central to our interests in this analysis, are the models designed to aid in the general planning and decision-making of an institution of higher education. Among these we consider both non-optimizing (simulation) and optimizing models. Second is a variety of special purpose models which treat a small part of a university's management decisions. These, too, may be either non-optimizing or optimizing, but they will be presented here according to subject. Finally, we shall treat briefly some of the macro-planning models which deal with education in a national economy, ranging from developing nations of Asia and Africa to the established nations of North America and Western Europe.

TABLE I: STRUCTURAL COMPARISON TABLE OF ANAL

FOR UNIVERSITY PLANNING

	FUNCTION			THEORY				METHODS															
				Behavioral		Growth Forces		Econometric-Stochastic			Simulation			Mathematical Programming							Financi		
	Derivation	Projection	Allocation	Market-Economic	Preference	Trend, Growth Index	Equilibrium	Input-Output	Markov Process	Regression	Autonomous	User Intervention	Monte Carlo	Linear Programming	Nonlinear Programming	Dynamic Programming and Optimal Control	Analysis of Uncertainty	Other	Student Flow	Faculty	Operating Costs	Operating Revenues	Capital Outlay
CAMPUS	X	X				X				X		X							X	X	X	X	X
RRPM	X	X				X				X	X									X	X		X
CSM	X	X				X				X	X									X	X		X
MSU	X	X		X		X	X	X	X		X								X	X	X		X
Tulane	X	X				X			X	X	X								X	X	X	X	X
CAP:SC	X	X				X			X		X								X	X	X	X	X
Thompson	X	X				X					X								X	X	X	X	X
Humboldt	X						X	X			X									X	X		
Menges-Elstermann	X	X	X						X					X		X			X	X			
Southwick	X	X	X	X	X	X			X	X								X		X	X	X	
Turksen-Holzman			X		X			X						X	X				X	X	X		
Oliver (student)		X				X			X										X				
Marshall-Oliver		X							X		X								X				
Marshall-Oliver-Suslow		X							X		X								X				
Dietze	X	X					X												X				
Caspar	X	X	X				X							X					X				
Oliver (faculty)		X					X				X									X			
Bartholomew		X					X				X									X			
Rowe-Weathersby		X	X		X				X	X						X	X			X			
Krings-Finkenstaedt	X																			X			
Braun-Hammer-Schmid	X						X	X												X			
Oliver-Hopkins-Armacost	X						X	X			X								X	X			
Halpern	X	X	X		X													X		X			
Smith			X														X						
Crandall		X	X	X										X									
Williams		X	X			X																	
Leimkuhler-Cooper		X	X			X												X					
Palmer-Wiederkehr		X	X			X																	
Fox-Sengupta-Sanyal	X		X											X			X			X	X		
Turksen		X				X			X										X				

I: STRUCTURAL COMPARISON TABLE OF ANALYTICAL MODELS FOR UNIVERSITY PLANNING

METHODS								SUBJECTS												DATA		USES						STATUS	
Simulation			Mathematical Programming							Financial					Administration and Support							Academic Planning							
Autonomous	User Intervention	Monte Carlo	Linear Programming	Nonlinear Programming	Dynamic Programming and Optimal Control	Analysis of Uncertainty	Other	Student Flow	Faculty	Operating Costs	Operating Revenues	Capital Outlay	Other Institutional Fund Sources	Physical Space	Libraries	Student Services, Aid, Activities	Other General Support	Organized Research	Public Services	Automated System	Special Purpose Collection	Staff	Curriculum	Fiscal Planning	Physical Planning	Scheduling	Manpower Requirements	Research Only	Currently Operational
	X							X	X	X	X	X		X	X	X	X	X	X		X	X		X	X				X
X									X	X		X		X	X	X	X	X	X		X	X		X	X			X	
X									X	X		X		X	X	X	X	X			X	X		X	X				X
X								X	X	X		X		X	X	X	X	X	X		X	X		X	X		X	X	
X								X	X	X	X	X	X	X	X	X	X	X	X		X	X		X	X			X	
X								X	X	X	X	X	X	X	X	X	X	X			X	X		X	X			X	
X								X	X	X	X	X		X							X	X		X	X			X	
X									X	X				X							X	X		X	X			X	
			X		X			X	X					X								X			X			X	
							X		X	X	X			X	X			X	X		X	X		X	X			X	
			X	X				X	X	X							X	X				X	X				X	X	
								X													X							X	
X								X													X							X	
X								X													X							X	
								X																				X	
			X					X																				X	
X									X												X	X						X	
X									X												X	X						X	
					X	X			X												X	X						X	
									X													X							X
									X													X						X	
X								X	X												X	X					X	X	
							X		X												X	X						X	
						X								X							X					X		X	
			X											X							X				X			X	
															X						X				X			X	
							X								X						X				X			X	
															X						X				X			X	
			X			X			X	X											X	X		X				X	
								X															X					X	

TABLE II: LOWEST LEVELS OF DISAGGREGATION A

	STUDENTS				FACULTY					FINANCIAL				PHYSICAL SPACE			
	Totals	By Level	By Discipline	By Department	Totals	By Rank	By Program	By Discipline	By Department	By Category	By Program	By Discipline	By Department	By Type	By Program	By Discipline	By Department
CAMPUS		X		X		X			X	X			X	X			X
RRPM		X	X			X		X		X	X	X		X		X	
CSM		X	X			X		X		X		X		X		X	
MSU		X	X		X					X				X			
Tulane		X		X		X			X	X		X		X		X	
CAP:SC		X				X			X	X			X	X			
Thompson		X				X				X				X			
Humboldt		X		X					X				X				X
Menges-Elstermann		X		X					X								X
Southwick																	
Turksen-Holzman																	
Oliver (student)		X															
Marshall-Oliver		X															
Marshall-Oliver-Suslow		X															
Dietze		X		X													
Caspar																	
Oliver (faculty)						X											
Bartholomew						X											
Rowe-Weathersby						X											
Krings-Finkenstaedt				X		X			X								
Braun-Hammer-Schmid		X	X					X									
Oliver-Hopkins-Armacost		X	X		X												
Halpern					X												
Smith														X			
Crandall	X													X			
Turksen		X	X														

TABLE II: LOWEST LEVELS OF DISAGGREGATION AVAILABLE

	STUDENTS				FACULTY					FINANCIAL				PHYSICAL SPACE				RESEARCH			
	Totals	By Level	By Discipline	By Department	Totals	By Rank	By Program	By Discipline	By Department	By Category	By Program	By Discipline	By Department	By Type	By Program	By Discipline	By Department	Totals	By Department	By Discipline	By Fund Source
		X		X		X			X	X			X	X			X		X		
		X	X			X		X		X	X	X		X		X				X	
		X	X			X		X		X		X		X		X				X	
		X	X		X					X				X				X			
		X		X		X			X	X		X		X		X				X	X
		X				X			X	X			X	X						X	X
		X				X				X				X							
		X		X					X				X				X				
		X		X					X								X				
		X																			
		X																			
		X																			
		X		X																	
						X															
						X															
						X															
				X		X			X												
		X	X					X													
t		X	X		X																
					X																
														X							
														X							
		X	X																		

A. Comprehensive University Simulation Models

The pioneering effort among the large-scale simulation models is the CAMPUS model, developed by Richard Judy and Jack Levine through the Systems Research Group [2, 8, 9, 50]. Origninally based on data from the University of Toronto, the CAMPUS model has been expanded and generalized to be applicable to virtually any college or university. Indeed, projects are underway which will adapt CAMPUS to community colleges, state systems, to colleges with completely individualized instruction, and even to elementary and secondary school systems. Thus, an outstanding feature of this model is its flexibility.

The model itself is capable of performing a variety of simulations for the user through its elaborate input and output routines. The user can specify precisely which data are to be supplied as inputs, whether as user-estimated parameters or as decision variables, which parameters are to be estimated from time series analysis using regression or exponential smoothing; and which are to be calculated, and reported as output. For example, enrollment figures for future years can be estimated by the user and supplied as inputs, or they can be projected by the student flow model provided. The user can specify whether he wants to know average costs, or marginal costs (e.g., the cost of changing enrollment in a given department by some increment). The model can compute resource requirements and costs at any level of aggregation: by program, by department or even by activity (such as a single lecture or laboratory session). The X's in Table II indicate the lowest level of aggregation and CAMPUS can provide virtually any subtotal based on these elements.

Such flexibility, however, usually requires a model to assume a massive

size, and to require enormous amounts of data. To alleviate this difficulty, the model is constructed so that most of the data needed are normally collected by institutions. In addition, the computer program is resident on a large time-sharing utility with each user terminal equipped with cathode-ray tube display, printer, keyboard and access to the entire program. The data of each user is stored on protected files, and continuously updated. Furthermore, by defining the institution's various activities at a higher level of aggregation, it is possible to set the level of detail and therefore to determine the amount of data required by the CAMPUS system. Thus, if one wished to have a highly aggregative model with minimum data requirements, it would be possible to do so by the appropriate definition of activities. It is the activity concept which gives CAMPUS its great flexibility to handle practically any level of aggregation or disaggregation. It is an important (and still open) question whether or not the reliability and utility of the output of the model for institutional decision making is sufficient to justify the expensive accumulation of detailed data down to the activity level. However, CAMPUS is also designed to provide information to decision makers at the level of department chairmen, program directors or deans. This requires extensively disaggregated variables which reflect the reality of each decision maker's department, program or college.

CAMPUS in its latest form (CONNECT/CAMPUS), is the most detailed of the educational planning models currently available, although it is no more than a straightforward resource-costing model. Space requirements, personnel needs, student flows and support costs are included in the model, and an effort is currently underway to incorporate debt financing into the model by combining CAMPUS with the Space Cost Model of the State University of New York Construction Fund. Available in the present model are

analyses of environmental (exogenous) effects such as interest rates and inflation, when these forecasts are supplied by the user. Analyses of the research and public service programs of a university are currently missing, but could be included. In addition, CAMPUS has the only fully operational health sciences planning model currently available and this model includes an interesting application of linear programming for clinical staff allocation.

CONNECT/CAMPUS differs from the other general university decision models in one other important dimension—the man-model interface. This system is essentially a computer aided instruction software package which assists the user to experiment with, alter and interpret the model without any programming experience. This feature is potentially a great benefit both in the instruction of analysts and in the analysis of institutional decisions.

Somewhat less ambitious than CAMPUS in level of detail but containing explicitly many useful features not usually found in that model is the Resource Requirements Prediction Model (RRPM), [13] developed by Mathematica for the Western Interstate Commission for Higher Education (WICHE), and based on the Cost Simulation Model (CSM) of the University of California [12]. Like CAMPUS, RRPM is a simulation model, but unlike CAMPUS, it is oriented principally toward institutional costs and finances. Indeed, this model includes considerations of the fund flows of capital outlay extending over a period of time, while at present, CAMPUS treats payments as occurring at one instant of time.

The dynamics of RRPM are assumed to be linear, with the parameters estimated by regression analysis. As in CAMPUS, however, the user can override the normal mode of calculation and specify his own parameters. He does this by ignoring the output of the "analytical package" and entering

the "prediction module" directly. Thus, RRPM's modular structure provides flexibility, although to a lesser extent than CAMPUS. The data for RRPM are highly aggregated, which can result in a great saving of bulk when compared with the fully disaggregated form of CAMPUS, and they are data generally available from institutional files.

RRPM derives the faculty, staff and budgetary needs generated by a given set of policy decisions. Included in the model as available policy variables are the research and public service programs of the educational institution. The discipline categories used are those established by HEGIS, and the program structures (instruction, research, public service) are those defined by the WICHE Program Classification Structure.[10] An interesting feature of the RRPM (and CAMPUS) is the "induced-course-load matrix," which relates students by major field and level to courses demanded, by discipline and level of instruction. Among the modules available in CAMPUS but not in RRPM is a student flow module; hence, enrollment forecasts must be supplied as inputs to RRPM over the planning period being considered. Such a module is, however, currently under development for inclusion in RRPM. The RRPM is being pilot tested in eleven institutions at the present time for further development and validation.

Like CAMPUS and all of these simulation models, RRPM is strictly a device to propagate the dynamics of the educational institution, as estimated by the analyst. There are, therefore, no evaluations of objectives in the model. The user of the model must somehow interpret the results of the simulation and, from this information, make his operating and investment decisions.

The "Systems Model for Management, Planning, and Resource Allocation in Institutions of Higher Education" was developed at and for Michigan

[10]WICHE, _op. cit._

State University by Herman Koenig and his associates [3]. It is a simulation model, complete with student flow projections, and derived faculty, personnel, space and budgetary requirements. Designed along the lines of linear systems, the model includes dynamic propagation, such as the Markovian student flow module, and equilibruim constraints of an input-output nature. The parameters of the linear dynamics and the production coefficients of the MSU model are estimated from past data. Hence, the effects of many important controllable variables are lost in the parameters of the model. In terms of user intervention, this model is not as flexible as either the CAMPUS or RRPM models, which is a serious drawback. The MSU model is fairly comprehensive, including students, faculty, support needs, services, facilities and costs. Included is a course credit distribution matrix, which relates students, by field, to course demands, and which is similar to the "induced course load" matrix of RRPM. No attempt is made to quantify measures of output other than costs and degrees awarded, so that the usefulness of the model in institutional decision making is limited. In the final report, however, the authors recognize this limitation and the user is urged to consider factors outside the scope of the model before reaching a final decision. The authors do not, however, propose any further work at quantifying these ostensibly unquantifiable variables, such as the intrinsic value of education of a given quality, public services and pure research.

Some of the more attractive features of the model are its amenability to decomposition, or suboptimization by sector, and an analysis of the sensitivity of outputs to varying parameters. This is an expensive way of compensating for the problems resulting from disguising control variables as endogenous parameters. The authors propose a massive overhaul of the data systems of universities which would facilitate implementation of the model;

in other words, much of the data needed is not generally available at institutions at the present time in the form required.

It is worth remarking at this point that this model, because of its rigorous structural form, lends itself to optimization techniques. However, optimization would be meaningless unless the controls are properly identified and unless the most important outputs of an educational institution are considered.

This model does not consider explicitly the effect of price indices as an exogenous variable, but disguises this effect in input-output ratios. As in the University of California CSM, CAMPUS and RRPM, however, price effects can be removed prior to regression and the constant dollar results subsequently inflated. This points out the need to identify exogenous variables of significance, as well as control variables.

For purposes of later discussion, we note that the authors of the MSU model propose, in addition, a simple linear model of education in a national economy, relating manpower needs with university outputs. More will be said about this in the section on national educational planning models.

The Tulane University Model [1] is essentially a resource costing model designed specifically for a nine-year planning period. Data for the first five years on student enrollment, faculty by rank and pay scale, teaching load, faculty salaries and section size are analyzed by linear regression to generate projections for the next four years. One of the central features of the model is the calculation of faculty salaries, elaborately performed on the basis of weighted Full Time Equivalent faculty by activity, rank and pay scale. Support and facilities costs are not computed by such elaborate procedures, and fixed ratios based on previous data are used to derive costs other than faculty salaries. Student flows are the basis for

predicting faculty requirements, and these are derived by a Markovian model which uses the data of years 1 - 5 to predict years 6 - 9. Research and public services are not treated carefully.

Controls available to the user are section size policy, new enrollments, faculty duties and division size. In fact, the model is well-suited to sub-optimization at the divisional level (engineering, arts and sciences), because divisional contributions to total expenses are itemized. Other variables, normally controllable, are treated as outputs, determined by multiplying a time independent constant by some other expense or enrollment variable. This weakens the applicability of the model considerably by underestimating the control of the "decision maker," but this is a failure of many of the large models we have seen. The strongest points of the Tulane model are its faculty salary-allocation procedure, its inclusion of "time-scale parameters" which project price indices for years 6 - 9 on the basis of data for years 1 - 5, and the availability of most of the required data from institutional files. The model is inappropriate, however, for a formal consideration of optimal resource allocation decisions, because of the lack of a causality structure describing the interrelationship of the variables. It is most useful as a predictor of faculty costs as a function of student enrollment, and of current costs as a function of price indices.

With most of the major simulation models apparently directed toward the large universities, the firm of Peat, Marwick, Livingston, and Co. saw a need for a model to aid in planning for small colleges. In response, they created CAP:SC (Computer-Assisted Planning for Small Colleges) [6]. It remains to be seen whether it is a worthwhile expense for a small college, with a relatively simple institutional structure, to invest in a decision model of such magnitude.

The CAP:SC model carefully distinguishes among state, control and exogenous variables, and generates the state variables dynamically from the previous state variables and the user-supplied controls and exogenous inputs. As in the other models we have considered thus far, there is no internal structure to analyze the uncertainty in the exogenous inputs; a simulation must be run for every different set of values for exogenous variables. The major components of the model are: student flow, faculty flow and an unusually complete treatment of costs and income generation which distinguishes this model from other general costing models. Most of the relationships in the dynamics of the model are definitional, and therefore exact, but many are estimated relationships. Most of these are estimated by intuitive techniques, although statistical curve-fitting is occasionally used. One interesting example of their use of regression analysis is in the estimation of the course-demand pattern.

The level of aggregation is high, which is appropriate for long-range planning, and is justified because any lower level of aggregation would reduce to a collection of mostly ones and zeros for a small college like the eight affiliated with CAP:SC development. The user can interact only to the extent that he may select as outputs any of the state variables for any desired periods. Otherwise there is very little flexibility.

A major value of this model is that its dynamic structure is easily adaptable to control theory analysis both of the uncertainty in the dynamics and of the value of the output, although the model itself includes analysis of neither uncertainty nor outputs. It is worth noting, finally, that included among the state variables are descriptions rarely found but certainly needed in these models, such as the amount of research accomplished, and income received. Public services are not among the outputs of the model.

The model of Robert Thompson of the University of Washington [10] is highly aggregated and rather simple, but it possesses several significant features absent in most other simulation models. The university is divided into three sectors: students, faculty and space, all highly aggregated, and inter-related by user-supplied student/faculty and student/space ratios. Costs are calculated from faculty and space requirements, but consideration is given to the dynamics of financing, faculty hiring, and other activities by explicitly recognizing time lags, which is more realistic than assuming instantaneous effects of decisions. In addition, a cost index adjusts annual prices in accordance with an exponential growth schedule.

The Humboldt State College Input-Output Model [4] is very modest in scope and purpose. Using past data, which may incorporate many previous policy decisions, the model linearly generates required facilities, by type, from the number of students, by major field. From there, operating costs are calculated, so that the annual cost of educating a student body of a given mix of fields can be estimated.

B. University Performance Optimization Models

Thus far, there have been few efforts at developing comprehensive decision models for higher education which incorporate preference structures into the formal model.[11] There are many optimizing models, typically of the linear programming variety, which treat a small part of a university and suboptimize a particular sector under externally given constraints; but model builders have tended to avoid including objective functions in large scale planning models. One reason for this is that it is difficult to quantify most of the outputs of a university, and for that reason, model builders prefer to leave out considerations of value rather than impose an imprecise or incomplete objective function on the problem. This is probably an appropriate reaction to the practice of chopping the complex outputs of a university to fit the procrustean bed of a linear preference function, but it is not necessarily appropriate to avoid the analysis of outputs entirely. We review here one large-scale optimization model of each type, and one compromise: the linear programming university management model by Menges and Elstermann of the University of the Saar [5], the model developed by Lawrence Southwick, Jr. at the Carnegie Institute of Technology [7], and the tentative model of Turksen and Holzman [11]. All of these are only research efforts, and all are too aggregated to be of direct use to an institution in their present form, but the structure of these models is of interest because it might be appropriate to incorporate their methodology into a larger system such as CAMPUS or RRPM.

The capacity model of Menges and Elstermann was developed for German university management, and may therefore not be entirely appropriate for

[11] See Richard F. Barton [47], for a discussion of optimization models in American universities.

American universities both in terms of data requirements and in terms of objective orientation. The model is a linear-dynamic model, complete with student flow matrix, participation matrix, and capacity and faculty requirements. The problem is formulated as a system of linear capacity constraints, with the linear objective function placed on the admissions vector of students for each year of the planning period. It seems that it would be more appropriate to associate value with output, or at least with the vector of graduating students. This apparently reflects the emphasis in this model on finding a feasible solution--that is, an admissions policy which satisfies the "capacity" constraints on space, faculty and expenditures--and not on the evaluation of objectives. The level of aggregation of variables in the Menges-Elstermann model ranges from specific designation of courses on one extreme to aggregation of all material resources on the other! Here, in summary, is an example of an interesting and potentially useful academic planning model of the capacity constraints of a university with little or no analysis of costs, policy alternatives or benefits, and, finally, an objective function defined over inputs rather than outputs.

On the other hand, Southwick's model is a carefully formulated dynamic model of the university. It is very aggregated and, consequently, is not suited in its present form for practical decision analysis within an institution. (For example, students are distinguished only as undergraduate and graduate students.) Nevertheless, the author's expressed intent was only to develop a model suited for rough evaluations, which could later be expanded to account for details. Regression is used to estimate all production relations, and care is taken to justify linearity where it is assumed. There is no student flow analysis, but this could easily be added to the model if desired. In short, the model is large in scope but modest

in size, the author being cognizant of the false precisions often inherent in the detailed, disaggregated simulation models.

Southwick's model is designed so that objectives can be evaluated by a utility function. The high level of aggregation makes this feasible, and the result is a significant research effort. Unfortunately, the quantitative data used in his analysis are average data drawn from many universities, so that the actual results of his run were not very meaningful. Nevertheless, his work points the way toward a model which would include careful evaluation of outputs as well as a simulation of the university dynamics. The premise is that it is better to make well-founded decisions based on aggregated data than to accumulate enormous quantities of detailed output and have no analytical aid in interpreting it.

To conclude this section, we note the work of Turksen and Holzman. Their model is also purely conceptual, and is too aggregated and general for specific use. It is an activity-oriented analysis, which results in linear constraints. The authors suggest linear and quadratic objective functions and little indication of how to deduce them from real institutional or individual objectives. Their treatment of objectives is clearly more reasonable than that of Menges and Elstermann since some intuitive rationale is given for the use of the quadratic, rather than the linear, preference function. The proposed model does not, however, treat objectives as carefully as Southwick does. Unfortunately, none of the three optimization models we have discussed has been tested with real objective functions of university decision makers. The Turksen-Holzman model is of particular value because its subject is essentially curriculum planning, in which the authors attempt to determine how many and what kinds of courses to offer in a given term of study. On the basis of our investigation, this

sort of analysis is rarely found in the literature of university planning models. Finally, we note that costs are hardly considered at all in the Turksen-Holzman model, while research and "other programs" are included in aggregated form.

C. Special Purpose University Planning Models

1. Student Flow Models

Robert Oliver has developed a series of research reports, prepared at the University of California, Berkeley, dealing with student flow and attendance. These models follow the work of Gani [20] and Young and Almond [35] and are designed to aid university decision makers in forecasting the effects of policies affecting admissions and attrition on actual enrollment and attendance. Oliver [29]; Oliver and Marshall [27]; and Marshall, Oliver and Suslow [25] represent a series of increasingly sophisticated Markov models, the latter two incorporating the possibilities of dropouts (absorbing states) and vacations. There is no explicit treatment of the estimation of parameters in the transition matrix. Presumably, these parameters could be viewed as statistically given from past data, or perhaps they could be viewed as partially controllable by such devices as failure rates or financial aid. Analysis of the propogation of uncertainty of student enrollment is included in Oliver [29], but is not applied to the two more complex models.

The Markov assumption central to these models is probably not entirely realistic for an individual student; for example, a student who has been promoted at every step is more likely to advance from step i to $i + 1$ than one who had to repeat step i before. These difficulties may or may not be averaged out by aggregating the data,[12] and some research is

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[12]See D. W. Breneman, "The Stability of Faculty Input Coefficients in Linear Workload Models of the University of California," Ford Foundation Research Program in University Administration, Research Report No. 69-4, University of California, 1968; J. B. Edwards and G. H. Orcutt, "Should Aggregation Prior to Estimation be the Rule?" Review of Economics and Statistics, Vol. LI, No. 4, November, 1969.

needed to test non-Markovian hypotheses. Of course, much of the mathematical elegance and computational ease is lost if the Markov property is not accepted, and therefore, it would be unwise to refect it unless it is found to fall significantly short of predicting reality.

Two German models, by Dietze [18] and Caspar [16], combine student transition matrices with course participation matrices to predict course demands in future years. The full development of these models is limited by the availability of data from German universities; indeed, the problem of inadequate data seems to be inherent in virtually all student flow models, which makes the explicit analysis of uncertainty even more desirable. Finally, it is worth noting that Caspar proposes a linear-programming solution for the optimal admissions vector, subject to given course-capacity constraints.

The student flow model of Turksen [33] is similar in purpose to the Dietze and Caspar models, but its analysis of uncertainty is more sophisticated. In addition, Turksen's model includes the possibilities of allowing for course prerequisites and eligibility of enrollment in a given course or program. This model is specifically designed to project course enrollments by department for the purpose of curriculum planning.

2. Faculty Staffing

a. Flow Models

Oliver [28] and Bartholomew [14] developed aggregated equilibrium models of faculty flows, including considerations of appointments, promotions and attrition. These models are intended to aid administrators and department chairmen in projecting the composition of faculty, by tenure and non-tenure.

Rowe and Weathersby [31] carried these ideas a bit farther by breaking down the faculty into four ranks (two tenured and two non-tenured), and formulated an optimizing procedure to evaluate the composition of faculty over a predetermined planning period. Linear propagation, estimated by least-squares regression, and quadratic performance criteria are combined into a control-theoretic approach to determine optimal faculty hiring. While the initial empirical results were incomplete, this was partially attributed to insufficient sample size (six years). Filtering was used to deal with uncertainty and to synthesize an optimal open loop controller. The performance criterion measured deviation from target values for the proportion of faculty by rank over the years covered by the model, as well as deviations from either the budget or the total faculty position available.

b. Faculty Staffing Requirements

Several models are available which compute the required or desired faculty size based on instructional needs. The Krings-Finkenstaedt [23] formula is no more than an identity which calculates the desired number of faculty, by field, from the student enrollment, teaching load, and desired student/faculty ratio which is supplied by the user. This model is of

interest mainly because it has actually been used at the University of the Saar. The model of Braun, Hammer, and Schmid [15], also developed for German universities, is little more than a disaggregation of the Krings-Finkenstaedt formula. Neither of these deals with optimality, nor do they consider faculty salaries or faculty flow. The BHS model involves an elaborate course participation matrix, to be supplied by the user, and presupposes that curricula by field are predetermined.

Oliver, Hopkins, and Armacost [26] depict the student-faculty interface by a network flow model, incorporating aggregate flows of students and faculty. Parameters are to be estimated from aggregated past data, but no clear estimation procedure is given. Although the model is designed primarily for deriving faculty requirements, a proposed performance criterion is given which measures the degree-granting efficiency of the institution. Being strictly an equilibrium model, this work is not amenable to dynamic planning, but it is helpful in deriving steady-state constraints on the student-faculty system.

The dynamic optimizing model of public universities by Halpern [22] assumes that there are two competing decision makers, representing the state authorities and the university administration. Each has tolerance limits on the student-faculty ratio, and the model computes hiring policies which satisfy both interests and which maximize the discounted performance criterion of the institution. The model is extended to a multi-campus university, allowing for flows of personnel between campuses. Like the other faculty-student models, the data is highly aggregated.

3. Other University-Related Planning Models

There are many sectors of the university which it is possible, indeed desirable, to model separately and independently to aid in the institution's management. We describe a few of these models here to illustrate the kinds of university activities and decisions that can be modelled.

Smith [32] proposes a course-scheduling algorithm which allocates classes to classrooms, by size, according to student demand for the courses. Crandall [17] has developed a linear-programming model to aid in a university's decisions regarding both construction of and subsidies for student housing. Morse [52], Williams [34], Leimkuhler and Cooper [24], and Palmour and Wiederkehr [30], have done extensive research in modelling libraries, including considerations of acquisition, circulation, demand, remote storage and associated costs. Fox, Sengupta and Sanyal [19] have proposed a linear programming model for departmental allocations within a university, under a variety of possible performance criteria.

D. National Educational Planning Models

It is not within the scope of this work to evaluate models which are not focused on the internal decision making of an institution of higher education. We shall, however, mention some of the more prominent models of educational systems at a national scale, if only because the methods used therein may shed some light on possible applications to university decision models.

Linear projection and student-flow models have been developed by The Forecasting Institute of the Swedish Central Bureau of Statistics [43], Thonstad [44], and Armitage and Smith [36]. UNESCO [45] has developed a linear resource requirements model, oriented toward manpower requirements in a developing nation. Kleindorfer and Roy [40] present a similar development model for East Pakistan. Models of American education have been constructed by Nordell [42], who uses an input-output structure to describe the California state educational system, and Koenig, et.al., [3], who briefly consider the relationship between the university and the manpower needs and the supply of the rest of the economy. Optimizing models for national planning have been proposed for France, by Bernard [37]; for Germany, by Weizsäcker [46]; and for Nigeria and Greece, by Bowles [38].

IV. CONCLUSION

Investigators of resource allocation decision making in institutions of higher education have approached this complex issue from a variety of disciplinary and practical perspectives. Southwick analyzed the university as a firm, Hoenig, et.al., modelled the institution as a phsyical system, while Nordell viewed education as a production sector of the economy. Currently, however, most applied models are more practical than conceptual in approach and rely heavily on statistically (or subjectively) observed relationships within institutions.

Our analysis of these models has brought to light several gaps in the range of existing applications of decision making technology to higher education. Some of these gaps are simply aspects of educational administration which have been largely neglected by existing models. Other gaps are more fundamental and include evaluation of objectives, analysis of uncertainty and treatment of decision making in an administrative hierarchy.

Specific Needs for Analysis

One area which desperately demands careful analysis is curriculum planning in a university. Richard Durstine [49] at Harvard has proposed very general procedures for dealing with these basic educational decisions, but no formal model has specifically included them. Involved in such analysis would have to be a careful evaluation of the educational outputs of a university, and the difficulty involved therein probably explains why models have failed to deal with these problems. In other words, the lack of formal analysis for curriculum planning is probably a manifestation of

the larger vacuum in the literature of all planning models: evaluation of objectives. We shall have more to say about objectives later on.

Returning to the specific needs of analysis for higher education, we note that of the models we have considered, only the one by Smith deals with the particular problem of scheduling. General purpose classroom scheduling algorithms have been developed in the past and have proved to be unrealistic and unworkable, largely because of the stochastic nature of student demand for courses. An effort is currently underway in California to combine many aspects of facilities scheduling and utilization with operating cost considerations.[13] This will enable educational planners to view the total cost of an institution as a function not only of academic planning parameters but also of facilities scheduling characteristics.

The explicit inclusion of manpower requirements is also rarely found in the literature of educational planning models at the institutional level, and the only good example we have found is the Oliver-Hopkins-Armacost model. Careful treatment of fund sources and revenues, as well as endowment management, is also needed, with enumeration at the level of detail of the CAP:SC model.

Before turning to the need for evaluation of objectives, we should remark that no model, even those currently operational, is driven by an automatic data system. The closest to that is the CAMPUS system, but even there the data must still be user-supplied. Peak efficiency in the use of models can be reached only when the entire data system is computerized. Koenig, et.al., propose such a system, but it remains to be seen whether progress toward that end is made.

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[13] This refers to the Coordinating Council for Higher Education's Facilities Analysis Model currently being developed by Mathematica, Inc., of Princeton, New Jersey.

Activities, Outputs and Objectives

A model can elaborately simulate the behavior of a complex system, but its ultimate purpose must always remain to aid in the making of decisions. Simulation models can trace the results of particular decisions or strategies, but this alone is of little use to the decision maker. At some point, he must face up to the question of what he wants, what are the important objectives, and how important are they? Without this kind of probing, the simulation might as well have never been performed. The justification for simulation models is that the decision maker must have some idea of his objectives and is able to compare the outputs of various simulation runs with each other and with his intended objectives. It appears to us that while detailed cost tracing is certainly a worthwhile accomplishment, using elaborate simulation techniques, only to apply haphazard "feel" techniques for evaluation, may well be counter-productive. What is needed is the systematic evaluation of objectives: hard thinking about trade-offs between competing and conflicting activities, and ultimately quantification of activities, outputs and objectives. Some consideration of objectives, however fuzzy, is better than no consideration at all.

The problem of evaluation can be subdivided into two segments. First, the objectives must be *identified* as independent criteria for evaluation--independent in terms of preference, not necessarily in terms of structure. Then, objectives must be *evaluated* according to relative importance, taking into account tradeoffs among them. Ideally, this second step should take into account uncertainty by evaluating uncertain outcomes as compared to equally-preferred "certainty equivalents." A careful simulation of the

dynamics of such a complex system as a university should be accompanied by a careful identification and evaluation of objectives, so that by combining these, a well informed and fully considered decision can be reached.

Some of the specific objectives which are difficult to quantify but in need of attention are educational output, research and public services. Indeed, WICHE[14] and many institutions have identified these as the three main programs of a university, but to date there has been little effort to quantify, or even evaluate, these outputs. Costs have been primarily considered, partly because they are more easily quantified and partly because there is more agreement over their definitions. If educational planners are to use models confidently, they must be encouraged to think hard and long about their basic goals, to insure that their decisions do more than minimize costs.

On the other hand, what optimizing models we have found tend to use a linear objective function.[15] This is done for two reasons: it is easier to solve the mathematical programming problem if the objective function is linear; and it is easier to synthesize a linear performance criterion because one need do little more than rank the objectives. Unfortunately, linear preference functions do not always approximate the decision maker's preferences. They should be used only when the optimizing problem is impossible to solve computationally under any other functional form, *but not as a substitute for careful consideration of objectives.* Quadratic preference structures are also amenable to analysis, and may be better approxi-

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[14] B. Lawrence, G. Weathersby and V. Patterson, Activities, Outputs and Objectives of Higher Education: Their Identification, Proxy and Measurement, WICHE, 1970; particularly the paper by F. E. Balderston entitled, "Thinking About the Outputs of Higher Education," Ford Foundation Program for Research in University Administration, Paper No. P-5, University of California, Berkeley.

[15] For further examples of the use of a linear criterion function, see J. E. Bruno, "A Linear Programming Approach to Position-Salary Evaluation in School Personnel Administration," The RAND Corporation, 1969.

mations to preferences, at least piecewise.[16] Nevertheless, no model incorporates a realistic, well-thought-out analysis of preferences. Southwick proposes something along these lines, but his analysis of preferences is not a working part of his model.

Another issue to be considered in the choice of an analytical representation of an institutional objective function is the process by which the decisions are reached. Most academic and planning decisions are the product of a committee, council, board or other group process. Consequently, the operational value structure for an institution will probably be more diffuse and smooth than for an individual. Therefore, one should remain skeptical of severe criterion functions, often used in analytical modeling.

Uncertainty

If the treatment of objectives in existing educational planning models has been weak, then the treatment of uncertainty has been weaker. Under the theory that repeated simulation is an acceptable substitute for analysis of uncertainty, most existing models fail to use any of the available techniques for dealing with stochastic systems. Part of the reason for this is that such analysis is most useful when outputs are quantified in a probabilistic utility structure.[17] Only under such circumstances is it valid to optimize expected value of the performance index.

Uncertainty enters into many aspects of the decision analysis. A complete analysis of all of these aspects for a given problem would be an impossible task. A reasonable strategy would be to determine to which

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[16]For a full discussion of optimization in economic and social systems including examples from higher education, see J. K. Sengupta and K. A. Fox, Optimization Techniques in Quantitative Economic Models, American Elsevier Publishing Co., New York, 1970.

[17]See H. Raiffa, Decision Analysis, op. cit.

elements the optimal solution is most sensitive, and then analyze these as uncertain while keeping the others at some "best guess" deterministic value. Optimal sampling schemes could be devised to improve estimates of these most crucial elements.

Perhaps the most difficult source of uncertainty in a social system such as a university is the identification of the system itself. Regression or exponential smoothing are often used to estimate the system equations, but they have pitfalls. Regression analysis typically minimizes a quadratic loss function given a specification of the functional form. If either the decision maker's loss structure is not quadratic or the functional form is misspecified, the regression results will be inaccurate and possibly misleading. This problem is compounded because there is no analytical way of testing the validity of the assumed loss structure or functional form. Furthermore, as it is commonly used, regression analysis assumes that various components of an institution which are modelled separately are statistically independent. It is not unusual, however, for essentially the same group of people to make decisions in a number of areas ranging from admissions, to faculty workload, to student aid, to library operations. Finally, the use of the results of regression analysis in future planning presumes that the institution will continue to operate on the same functional bases as before. A more accurate assumption, it seems to us, would be that the institution will evolve and change in many unpredictable ways. Therefore, some form of adaptive control,[18] however unsophisticated, may in many cases be preferable to a blind application of regression.

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[18] See R. Bellman, Adaptive Control Processes: A Guided Tour, Princeton University Press, 1961.

Bureaucratic and Institutional Structure

Underlying most of these models is the assumption that there exists a known decision maker with the appropriate set of controls at his disposal. In fact, a university is a complex bureaucracy with a hierarchy of decision makers each with his own degree of control and his own preferences. Analysis is needed, therefore, on two further grounds. First, following the works of Downs, Olson, Buchanan and Tullock,[19] a bureaucracy should be a part of the process of the system description. Second, the planning and allocation decisions should be viewed as complex hierarchical group decisions, perhaps with the aid of game thoery,[20] or at least outcomes and controls should be associated with their respective controllers. Halpern has developed this sort of strategic analysis, but has not dealt with the problems as fully as might be desired for use by a university administrator. The very interesting work of Geoffrion [21] has dealt explicitly with hierarchical decision levels and revealed preference, with the highest administrator's preferences defined over the utility of each sub-manager.

Summary

Up to the present, most models have tended to be simulations of educational systems, with outputs left dangling for haphazard evaluation at the end. A step in the right direction could be to run simulations but with some

[19] A. Downs, Inside Bureaucracy, Little, Brown & Co., 1967; M. Olson, The Logic of Collective Action, Harvard University Press, 1965; J. Buchanan and G. Tullock, Calculus of Consent, Ann Arbor, 1962.

[20] One could analyze institutional decision making with the paradigm of static games as in R. D. Luce and H. Raiffa, Games and Decisions, Wiley, 1957, or recognize the dynamic character of decisions and use the results of dynamic game theory as in A.E. Bryson and Y.C. Ho, Applied Optimal Control, op.cit., Chapter 9. Hierarchical, dynamic and optimal decision systems are analyzed in G. B. Weathersby, "The Allocation of Public Resources: A Decision and Control Theory Analysis," op.cit., Chapter 4.

framwork for evaluating the outputs. Included in this category would be Monte Carlo analyses of dynamic-stochastic systems. Even a well-thought-out plus-and-minus rating system for outputs is better than no rating system at all.

After performance criteria have been assessed with some practical and intuitive success, optimizing models may be in order. Such models may uncover new strategies which achieve better performance (or better expected performance) than any other strategy recognized by the decision maker. Optimization models are analytically complex and are often quite expensive to solve. Generally, the private sector experience has been that it is economically infeasible to use optimization models unless (1) the solution procedure is inexpensive (e.g., the linear-quadratic case in control theory), (2) there is little or no uncertainty, or (3) the decision involves an unusually large commitment of resources.

We have argued elsewhere[21] that the appropriate detail for analysis for most educational resource allocation decisions is no more than the proper conceptualization of the problem including the range of viable alternatives. Our society's current fascination with and implicit faith in computers, [illegible]usiastic claims of consulting firms, and demands for convincing accountability from state and federal agencies have all led to educational managers seriously considering the adoption of analytical planning models. Some of these models have proved to be very useful in associating various costs with proposed activities. Unfortunately, virtually all models have correspondingly focused on inputs to the exclusion of outputs and most models ignore institutional values, uncertainty and institutional

[21] G. B. Weathersby, "Educational Planning and Decision Making: The Use of Decision and Control Analysis," Ford Foundation Research Project in University Administration, Paper P-6, University of California, May, 1970.

decision structures. These areas could profit greatly from further research and analysis.

Another important consideration is to what extent an analyst redefines the problem to fit his analytical technique as opposed to modifying the technique to fit the problem. The optimization techniques of linear programming and open loop control theory are often applied to abstract problems because they give nearly exact solutions. A full analysis of the decisions available lead to a closed loop or dynamic programming solution which is numerically infeasible for a problem of any realistic magnitude. An approximate solution such as differential dynamic programming[22] might prove very useful in preserving the essence of the problem while enabling a numerical solution.

The ultimate utility of these modeling efforts cannot be assessed at this time or by the researchers active in the field. The costs of suboptimal resource allocation are largely opportunity costs which many decision makers do not even recognize. In the political climate of some institutions, careful economic analysis may be viewed as counterproductive or dysfunctional by the administration, while careful political analysis may be extremely useful. The variety and diversity of institutions and institutional problems insure that no one model can be all things to all people. Recognizing that there is no panacea, we can still respond to particularly important problems by carefully constructed decision analysis which may include formal analytical models of the type we have discussed.

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[22] D. H. Jacobson, "New Second Order and First Order Algorithms for Determining Optimal Control: A Differential Dynamic Programming Approach," <u>Journal of Optimization Theory and Applications</u>, December, 1963.

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